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PELAGIC SHARK ABUNDANCE INDICES BASED ON FISHERY-DEPENDENT AND FISHERY-INDEPENDENT DATA FROM THE WESTERN NORTH ATLANTIC.

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SUMMARY

The temporal and spatial characteristics of fishery-dependent and fishery-independent observations of longline catch and effort in the western north Atlantic are described. These include research survey cruises and at-sea observer programs that have monitored commercial fishing trips aboard Japanese and U.S. longline vessels. General linear modeling (GLM) procedures are used to develop standardized indices of abundance for blue and mako sharks.

RÉSUMÉ

Le présent document décrit les caractéristiques temporelles et spatiales des observations, indépendantes ou non de la pêche, sur la capture et l'effort palangriers dans l'Atlantique nord-ouest. Ceci comprend des campagnes de recherche et des programmes d'observateurs en mer qui ont suivi les sorties commerciales de palangriers japonais et américains. Les processus de modélisation linéaire (GLM) sont utilisés pour élaborer des indices standard de l'abondance pour le requin peau bleue et le requin-taupe.

RESUMEN

El documento describe las características temporales y espaciales de las observaciones, dependientes e independientes de la pesquería, de la captura y esfuerzo de la pesquería de palangre en el Atlántico noroeste. Estas observaciones incluyen cruceros de investigación y programas de observadores en el mar que han realizado un seguimiento de las mareas comerciales de palangreros japoneses y estadounidenses. Para desarrollar índices de abundancia estandarizados para el tiburón azul e Isurus spp se han utilizado procedimientos del Modelo Lineal Generalizado (GLM).

1. INTRODUCTION

The United States National Marine Fisheries Service (NMFS), and its predecessor the Bureau of Commercial Fisheries (BCF), have conducted periodic longline surveys off the east coast of the United States since the late 1950's. Surveys first targeted tuna and swordfish along the edge of the continental shelf, and subsequently focused on pelagic and coastal sharks over a variety of depths, including inshore bays and estuaries. The NMFS and the Department of Fisheries and Oceans (DFO) in Canada established observer programs to monitor Japanese vessels fishing within their respective Exclusive Economic Zones (EEZs). While the U.S. program lasted from 1978 to 1988 when the Japanese discontinued fishing in the U.S. EEZ, the Canadian program continues to this day. More recently, NMFS has deployed observers to monitor U.S. fishing vessels with longline permits for swordfish, shark, or tuna. These vessels operate throughout the western North Atlantic and observers have been deployed since 1985. Mandatory deployments since 1990 are based on random vessel selection by quarter and area from effort reported in mandatory logbooks for the previous year. Additionally, opportunistic deployments of scientists aboard U.S. and Canadian commercial vessels have occurred periodically during the 1970s, 1980s, and 1990s in response to specific research projects relating to gear studies and/or biological sampling opportunities.

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This report describes an ongoing project to electronically archive historical longline survey data and to reconcile that data with more recent fishery-dependent observations. Describing the temporal, spatial, and operational characteristics of the surveys and commercial operations as well as the multi-species catch provides an opportunity to better understand distribution patterns and the relative vulnerability of target and non-target species to different fishing practices. Evaluating fishing characteristics and catch rates from overlapping time-series provides an opportunity to assess abundance trends for several target and non-target (bycatch) species.

2. MATERIALS AND METHODS - DATA SOURCES

Data from research survey cruises, U.S. and Canadian observers aboard Japanese vessels, and opportunistic deployments were coded as consistently as possible with the more detailed recent mandatory observer data. Not all of the gear and operational variables currently recorded by observers were recorded aboard Japanese or survey vessels. Species information and the types of variables recorded for each animal caught varied between programs (e.g. counts by set versus total weight by set). Set specific gear, deployment, retrieval, and species composition data were coded from original cruise reports, field fishing logs maintained by scientific personnel, or final grant reports. Missing data elements were recovered from original observer forms. Outlier identification programs were run on most of the variables that were consistently recorded and data were edited when necessary. The following briefly describes the survey and fishery dependent data that are included in subsequent analyses:

1) RESEARCH CRUISE DATA - A total of 2,294 sets were accumulated from research cruise sources. These included the following: 1) 405 sets by the Bureau of Commercial Fisheries (BCF), Woods Hole Oceanographic Institution (WHOI), and National Marine Fisheries Service (NMFS) targeting tuna and swordfish in offshore areas between 1957 and 1967; 2) 1,770 sets by NMFS during inshore and offshore shark surveys between 1961 and 1996; and 3) 119 sets from opportunistic deployments of scientists aboard volunteer commercial vessels.

2) U.S. OBSERVERS ONBOARD JAPANESE VESSELS - A total of 5,640 sets were recorded by U.S. observers aboard permitted Japanese vessels fishing within the US EEZ. Observers covered fishing activity in the Gulf of Mexico between 1978 and 1981, and areas off the southeast and northeast Atlantic coasts along the edge of the continental shelf and on Georges Bank between 1978 and 1988. US regulations prohibited possession of swordfish, billfish, and sharks and these were discarded (released) after their status (dead or alive) was recorded.

3) NMFS DOMESTIC OBSERVER PROGRAMS - A total of 4,747 sets were recorded by U.S. observers who were deployed aboard volunteer commercial vessels or those permitted vessels randomly selected for observation. These included the following: 1) 4,115 sets between 1990 and 1999 by Northeast (NEFSC) and Southeast (SEFSC) fisheries science center observers; 2) 435 sets by contractors hired by Louisiana State University (LSU) to observe Gulf of Mexico longline vessels, especially those targeting yellowfin tuna, between 1987 and 1991; and 3) 197 sets by observers opportunistically deployed during 1984, 1985, and 1986 aboard commercial swordfish and yellowfin tuna vessels. These sets are in addition to those opportunistic records identified in the survey data set.

4) CANADA - DEPT. OF FISHERIES AND OCEANS (DFO) OBSERVERS ONBOARD JAPANESE VESSELS - A total of 5,545 sets were recorded by Canadian observers who were required aboard permitted Japanese vessels fishing within the Canadian EEZ. To date, sets between 1986 and 1995 have been converted to formats consistent with the preceding data sources. Observed sets from both before and after the 1986 to 1995 time period may be recoverable. Catch information was recorded as the total estimated weight of a specific species caught on a set, rather than the number of individuals for each species as in the preceding data sources.

3. SPECIES AND OPERATIONAL VARIABLES

Observers attempt to identify all animals that are caught or entangled by the gear. Invariably there are animals that are coded as unidentified or unknown, and others that can only be identified to species family groups such as tunas, billfish, sharks, or species groups such as hammerhead, mako, or thresher sharks. Between 80 and 90 unique codes are recorded for species, species families, species groups, and unclassified records, with 30 to 35 of these codes represented by 10 or fewer individuals in the recent US observer data. To simplify analyses and presentation of species composition data the original 80 to 90 codes are combined in this report into 22 categories that include the dominant target and incidentally caught (bycatch) species and species groupings (Table 1). In addition to recording the species composition on each set, observers currently record the status (alive, dead, or damaged), disposition (kept or discarded), and measure or estimate size (weight or length) of each animal that is caught. Biological samples for age and growth or maturity studies are taken along with information on tagged or recaptured animals.

Operating practices generally reflect targeting strategies that can influence catch rates for target and incidental species. Observers therefore record gear characteristics and operating practices along with location and environmental variables. Standard forms and recording procedures result in separate files for trip, set, gear, haul, and animal records that track more than 150 variables. These include the date, location (latitude and longitude), time, and sea surface temperature at the start and end of setting and hauling operations for each set. Gear information includes number of hooks set and hauled, gangion and dropper line lengths and construction, mainline length and construction, the number of hooks between floats, the use of ancillary gear including line throwers, lightsticks, radio-beacons, weights, and rattles, as well as hook sizes, pattern numbers, and bait information. Codes distinguish between pelagic and demersal sets, sets with deep-rigged gear that is fished over shallow water depths (near-bottom or semi-pelagic), sets that use line throwers, sets with live bait, and sets where the gear is tended during the soak period. A lunar index based on the proportion of the lunar surface that was illuminated on a specific date was assigned to each set based on astronomical calculations referenced by Bigelow, et. al., 1999 (files provided via personal communication Keith Bigelow).

4. GENERAL LINEAR MODELING (GLM) - STANDARDIZED CATCH RATES

It has become a standard approach in stock assessments to utilize General Linear Modeling (GLM) to evaluate fishery independent and fishery dependent catch rate observations. Depending on the nature of the catch rates, especially the frequency of zero observations, different GLM methods are used. Recent assessments for north Atlantic bluefin and swordfish conducted by the Standing Committee on Research and Statistics (SCRS) of the International Commission for the Conservation of Atlantic Tunas (ICCAT) use a delta-lognormal approach that separately evaluates log-transformed positive catch rates and the proportion of positive observations by aggregated levels of factors that can influence catch rates. These include geographical area, temporal period (month or quarter), and various operating practices. This approach is attributed to Lo et. al. (1992) and we have used computer code developed by Cramer and Scott (1997).

Catch rates were calculated as the number caught per 1,000 hooks for blue sharks and number caught per 10,000 hooks for mako sharks. In order to minimize the number of observations with zero catches and to focus the analyses on the temporal and spatial strata that account for the greatest proportion of the blue and mako sharks observed, single set records were selected for pelagic sets located north of 35°N latitude. This resulted in 13,095 observations from 1957 to 1999, accounting for 98.7% of the total number of blue sharks and 88.3% of the total number of mako sharks recorded for all records previously described. Bottom longline observations and sets south of 35°N latitude, account for most of the sets that were eliminated. The associated gear and operational variables included the following: year; source or target; month; standard SEFSC longline reporting areas (Cramer and Adams 1999); five bottom depth categories; twelve 2 hour periods of time during which setting commenced; four categories based on numbers of hooks set between floats (rig depth); four categories for the combined lengths of gangions and droppers (hook depth); and five categories for the percentage of lightsticks used by set. Simpler and more complicated models were applied to evaluate the stability of the resulting annual index values. The simpler model included year, source, area, month, and bottom depth. The complex model included year, source, twelve 5° squares for area, month, bottom depth, and categorical variables for set time, rig depth (hooks between floats), percentage lightsticks, and gear or hook depth. The complex model was run once for all data and then again for the more recent time period from 1978 to 1999.

5. RESULTS AND DISCUSSION

The geographical distribution of observed sets from each program are displayed in Figures 1 through 4 along with the species composition of the associated catches in Figures 5 through 8. In the species composition histograms for the survey data and for the observer data from U.S. vessels, the catch corresponding to effort directed at sharks is distinguished from effort targeting swordfish and tuna. Demersal sets were combined and the opportunistic trips were assigned to the appropriate fishery type. In the observer data from U.S. vessels, the 111 sets (out of 4,866) that targeted sharks accounted for a disproportionate catch of the Charcharhinid species, such as sandbar, dusky, blacktip and sharpnose, that are prevalent in near-shore shallow shelf areas. A similar pattern is evident in the survey data, where the coastal Charcharhinids are almost exclusively captured by the shark survey gear, whereas the shark catch associated with effort targeting swordfish and tuna in deeper slope and offshore areas is dominated by pelagic blue sharks. With respect to the Japanese observations from both the US and Canadian programs, blue sharks and lancetfish dominate the incidental catch. Differences between the proportions of different tuna species reflect differences in geographical effort distribution, with yellowfin tuna more prevalent in the US observations primarily because of the effort that occurred in the Gulf of Mexico.

The purpose and design of historical surveys for large pelagic species has varied over time, contributing to differences in species composition, catch rates, and styles of gear used. The initial BCF/WHOI surveys in the western North Atlantic during the 1950s and 1960s emphasized daytime pelagic longline sets for bluefin, yellowfin, bigeye, and albacore tuna (Wilson and Bartlett 1967). After the first two to three years, greater priority was placed on night-time sets for swordfish. The BCF/NMFS shark project started at the Sandy Hook, N.J. lab where the emphasis was on near-shore coastal waters and distributions of large Charcharhinid species implicated in attacks on humans. In the late 1960s, 1970s, and 1980s shark surveys adopted a broader offshore focus for studies on the distribution, abundance, and life history characteristics of blue and mako sharks. This effort overlapped to some extent with the earlier offshore surveys for tunas and swordfish, opportunistic deployments aboard commercial vessels, and observer deployments aboard Japanese vessels operating in the U.S. EEZ.

During the late 1980s and 1990s the shark surveys adopted a more systematic survey orientation, covering a broader range of depths and wider geographic range including effort south of 35°N within the U.S. EEZ. In this later survey mode, soak duration was shortened and in 1995 and 1996 the gear was changed to a complete monofilament rig deployed as demersal gear. Previous cruises used pelagic or semi-pelagic sets with multi-filament mainlines and Japanese style gangions and included a greater number of sets in the deeper offshore areas frequented by the commercial fleets targeting swordfish and tuna. These changes in the shark surveys were implemented just as the domestic observer program for the swordfish and tuna longline fleet became fully operational with a more systematic deployment protocol.

The discontinuities in the time series for different survey and observer programs make it difficult to evaluate selectivity differences between operating styles and complicate analyses that attempt to account for these differences in order to estimate relative trends in abundance. The time series of set observations for each of the survey and commercial fishing target strategies is displayed in Figure 9. This figure illustrates discontinuities resulting from survey programs that were discontinued, experienced irregular funding, or changed research objectives (tuna vs swordfish or inshore vs pelagic sharks) and gear characteristics over time. In addition to the annual differences in numbers of observations evident in the trend lines, the distribution of the annual observations by area and month has differed significantly in several of the time series. As an example, because of funding irregularities in 1996 only 24 sets were observed north of 35°N.

Standardized abundance indices for blue and mako sharks produced by general linear modeling (GLM) of catch rates are displayed in Figure 10 and 11. For both species, index 1 reflects the simpler model run with year, source or target, area, month, and bottom depth. Index 2 reflects the more complex model which includes the terms from the simpler model along with categorical variables for set time, rig depth, percentage of lightsticks, and gear or hook depth. Index 3 is the complex model applied to data from 1978 to 1999 only. Analysis of variance tables for the proportion of positive observations and positive CPUEs as well as the residual patterns indicate reasonable model fits. For blue shark indices the model r-square values ranged from .36 to .56 for the proportion positives and from .40 to .43 for the positive CPUEs. For mako shark indices the model r-square values ranged from .21 to .36 for the proportion positives and from .62 to .66 for the positive CPUEs[4].

The species-specific abundance indices highlight the discontinuities in the different time series of observations. Obvious outliers that are particularly evident in the earlier portion of the time series, such as 1971 and 1972 for blue sharks and 1977 for mako sharks, reflect annual samples that are limited in numbers of observations and consist of offshore survey sets that targeted pelagic sharks with no or very few commercial observations. The consistent decline in abundance values for 1996 reflect the previously mentioned small number of observations in the area north of 35°N, compounded with the elimination of the Japanese time series. The outliers indicate that inconsistencies in sampling effort are not being adequately accounted for by the standardization. Shifting stanzas of contiguous years provide an additional sign that sampling effort may have changed, especially when the proportional increase or decrease in the abundance index between adjacent groups of years would be inconsistent with the life history characteristics of the species and/or operating characteristics of the harvesting fleets. One example, is the low index values generated for blue sharks prior to 1967 which could reflect reporting bias or a change in catchability, possibly reflecting greater competition between target species (bluefin and swordfish) and the dominant blue shark bycatch during the early to mid 1960s when the longline fishery was just becoming established in the western North Atlantic. The apparent existence of a reasonably consistent stanza from 1978 to 1992 followed by a shift to a higher stanza from 1993 to 1999 in the blue shark indices most likely reflects the discontinuity between the available Japanese observations and the more recent observer coverage for the U.S. permitted longline fleet.

Where overlapping time series were sufficient, reasonably stable patterns were produced by the GLMs. The reasonably stable or slightly increasing pattern for the blue shark index throughout the late 1970s, 1980s and early 1990s most likely reflects the fact that while blue sharks have been caught in very large numbers, they have been primarily released alive in the western North Atlantic because market demand was extremely limited and fining has been prohibited by U.S. and Canadian laws. The mako indices reflect similar patterns of stanzas with an overall trend that is stable or slightly increasing during the late 1970s, 1980s and early 1990s. The mako catch rates are an order of magnitude lower (catch per 10,000 hooks) than the blue shark catch rates (catch per 1,000 hooks). While market demand for mako sharks has been higher, many have been released alive because they are frequently caught alive and are very difficult to handle. It might also be argued that mature mako sharks, which frequently exceed 300 to 400 kilograms in weight, are simply not retained by the pelagic longline gear or occupy different areas than the sampled fleets. The combination of limited historical landings for blue and mako sharks, high release rates, and their faster growth rates and higher litter sizes (documented in other sections of this volume) provide the simplest explanation for stable trends, when conventional wisdom has highlighted the susceptibility of shark populations to overfishing.

For both the blue and mako indices the recovery of additional Canadian observations aboard Japanese vessels from 1996 to 1999 will help address the question of whether the stanzas reflect sampling inconsistencies or actual changes in abundance. Additional observer records from other

[4] Additional analysis of variance tables and the Lo index values with associated statistics can be obtained from the senior author.

fleets operating in the north Atlantic (Canadian, Spanish, and Portuguese vessels) and the incorporation of self-reported logbook data may help increase the reliability of these abundance indices especially for the last two decades. While additional data recovery efforts may increase the number of records that are available prior to 1978, because of gear changes and the mercury restrictions which were in place in the U.S. from 1970 to 1978 there will likely always remain a period of years with very limited numbers of observations. It will therefore always be a matter of debate as to how best to relate the catch rates from the 1960's to those that have existed since 1978.

6. REFERENCES

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Table 1. Species and species group list used to summarize species composition for observed longline sets.

Common Name	*Scientific Name*	*Family*
Yellowfin Tuna	Thunnus albacares	Scombridae
Bigeye Tuna	Thunnus obesus	Scombridae
Bluefin Tuna	Thunnus thynnus	Scombridae
Albacore Tuna	Thunnus alalunga	Scombridae
Other Tunas		Scombridae
Swordfish	Xiphias gladius	Xiphiidae
Blue & White Marlin	Makaira nigricans Tetrapturas albidus	Istiophoridae
Sailfish, Spearfish and unidentified billfish	Istiophorus platypterus Tetrapturus sp.	Istiophoridae
Blue Shark	Prionace glauca	Carcharhinidae
Mako Sharks	Isurus sp.	Lamnidae
Thresher Sharks	Alopias sp.	Alopiidae
Porbeagle & Oceanic Whitetip	Lamna nasus Carcharhinus longimanus	Lamnidae Carcharhinidae
Silky Shark	Carcharhinus falciformes	Carcharhinidae
Sandbar Shark	Carcharhinus plumbeus	Carcharhinidae
Dusky Shark	Carcharhinus obscurus	Carcharhinidae
Hammerhead Sharks	Sphyrna sp.	Sphyrinidae
Other Sharks		Carcharhinidae & Squalidae
Skates and Rays	Primarily Dasyatis sp.	Dasyatidae, Rajidae, Mobulidae, & Myliobatidae
Lancetfish	Alepisaurus sp.	Alepisauridae
Oilfish and Escolar	Ruvettus pretiosus Lepidocybium flavobrunneum	Gempylidae
Dolphin Fish	Coryphaena sp.	Coryphaenidae
Other Species and unidentified animals		

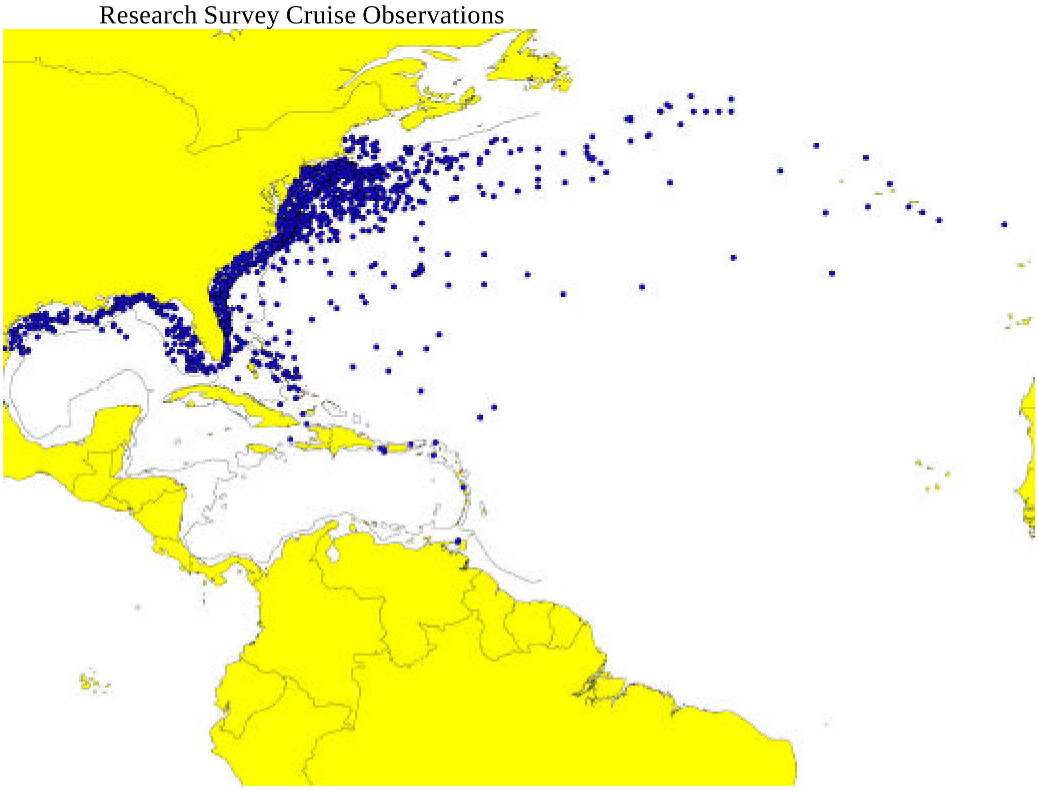

Figure 1. Geographic distribution of 2,294 longline sets (pelagic and demersal) recorded during research survey cruises between 1957 and 1996.

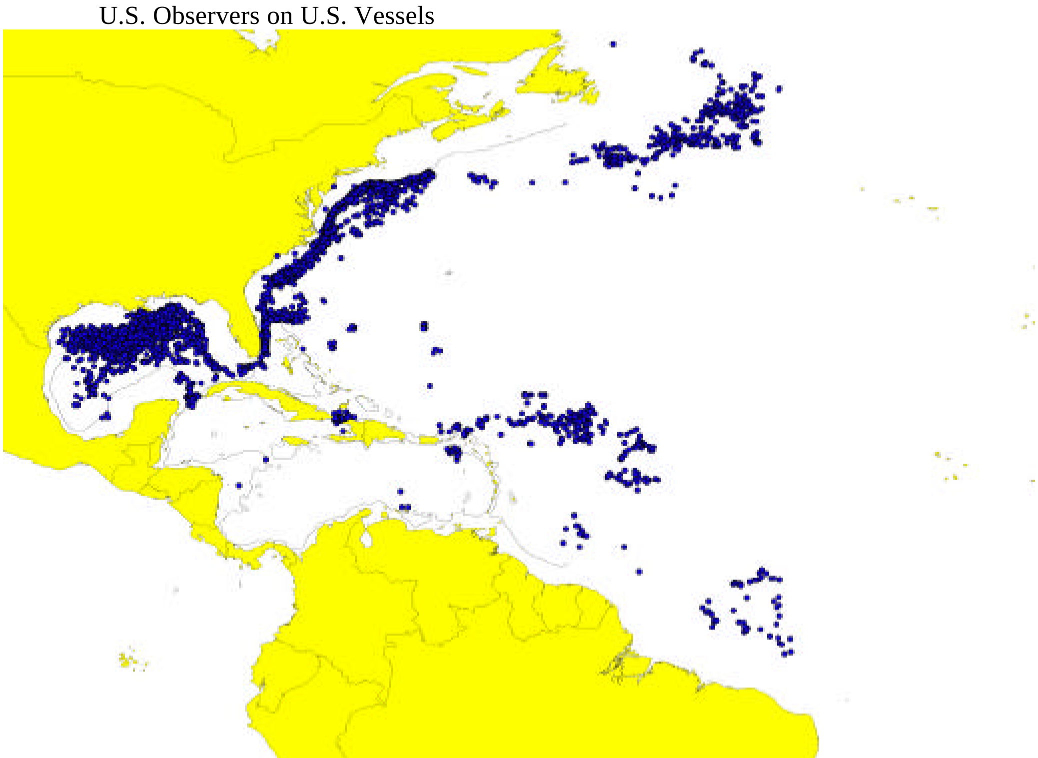

Figure 2. Geographic distribution of 4,747 longline sets (pelagic and demersal) observed aboard U.S. flagged vessels between 1990 and 1999.

U.S. Observers on Japanese Vessels

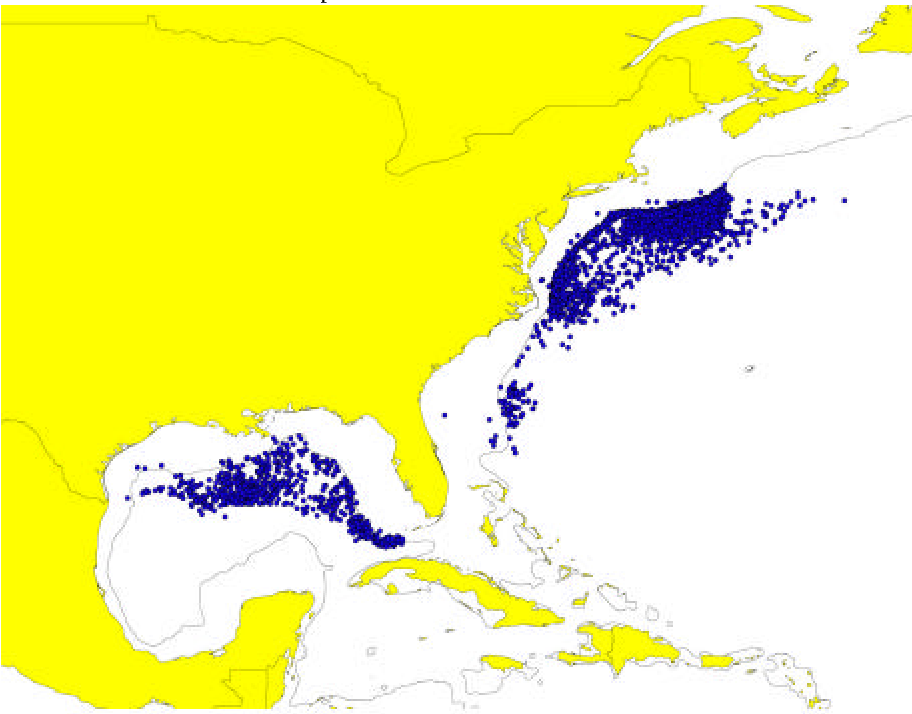

Figure 3. Geographic distribution of 5,640 pelagic longline sets recorded by U.S. observers aboard Japanese vessels fishing within the U.S. EEZ between 1978 and 1988.

Canadian Observers on Japanese Vessels

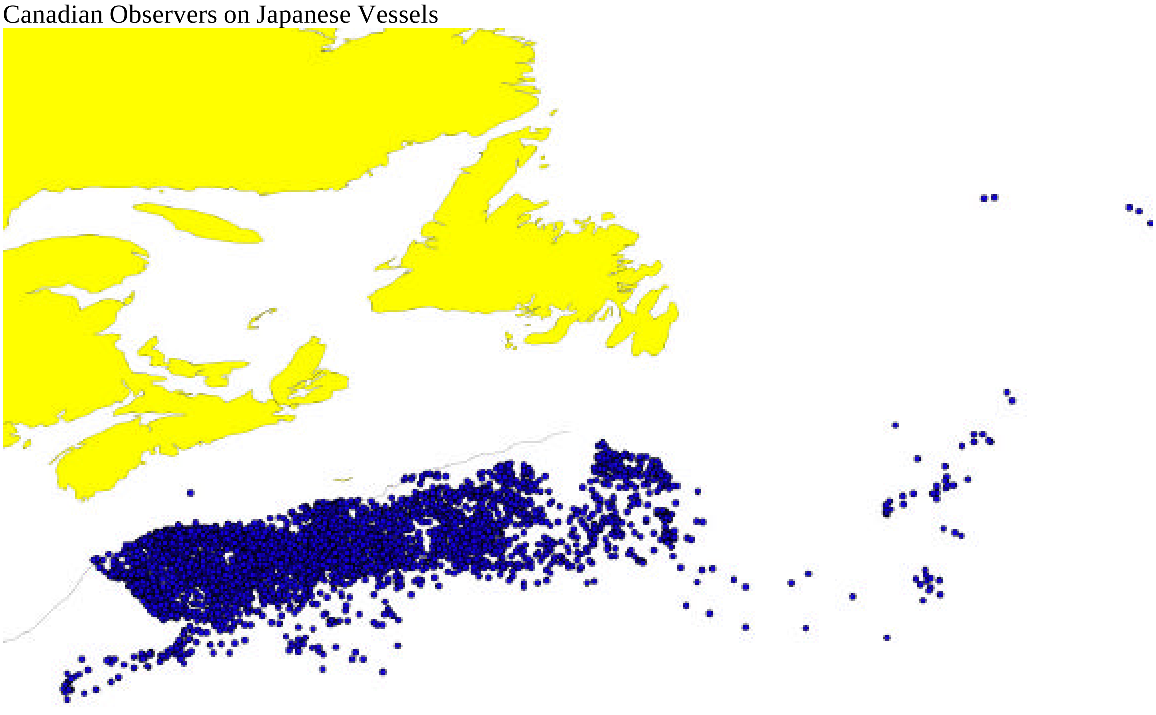

Figure 4. Geographic distribution of 5,545 pelagic longline sets recorded by Canadian observers aboard Japanese vessels fishing within the Canadian EEZ between 1986 and 1995.

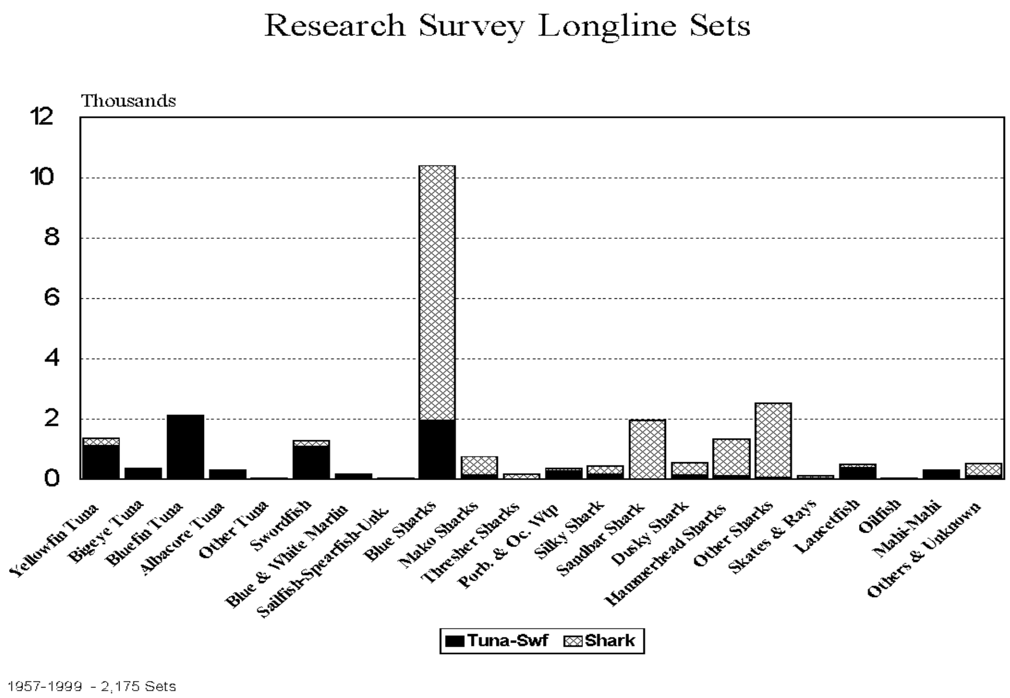

Figure 5. Species composition recorded on 2,175 longline sets (pelagic and demersal) during research survey cruises targeting tuna, swordfish and sharks between 1957 and 1996.

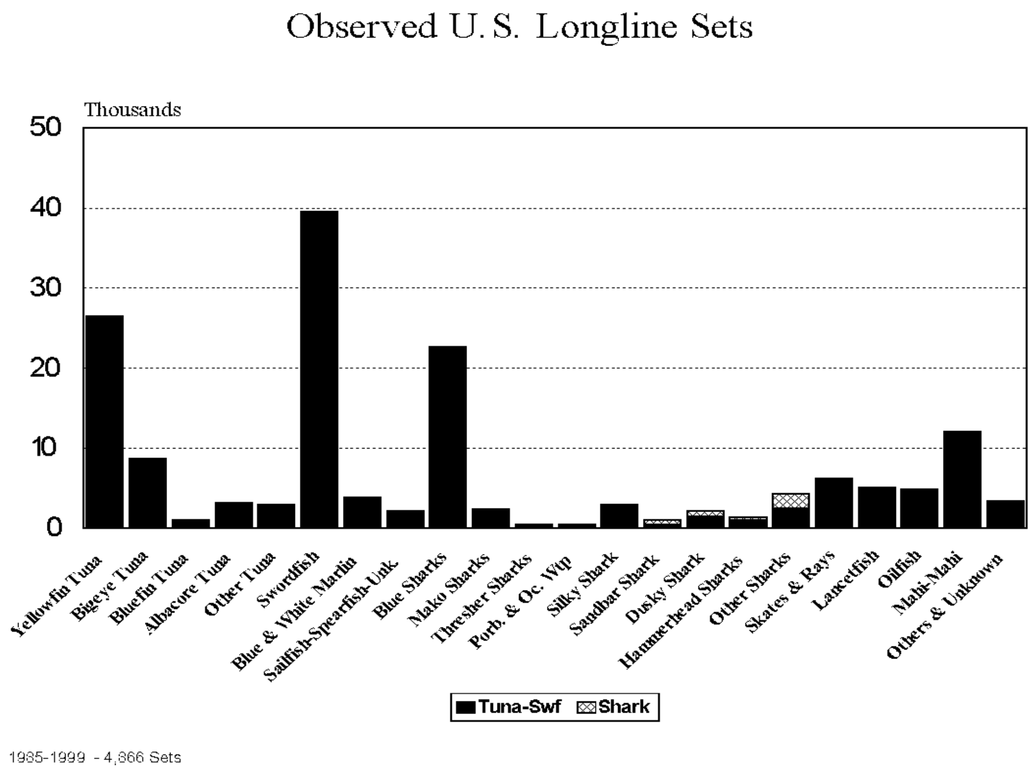

Figure 6. Species composition recorded on 4,866 longline sets (pelagic and demersal) observed aboard U.S. flagged vessels primarily targeting swordfish and tuna between 1990 and 1999.

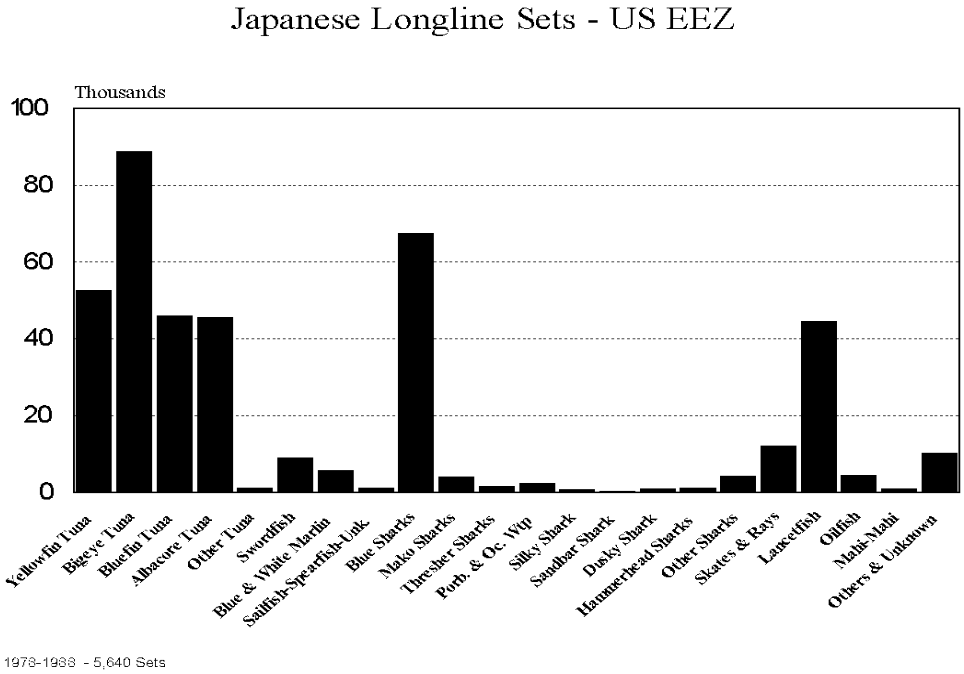

Figure 7. Species composition recorded on 5,640 pelagic longline sets monitored by U.S. observers aboard Japanese vessels fishing within the U.S. EEZ between 1978 and 1988.

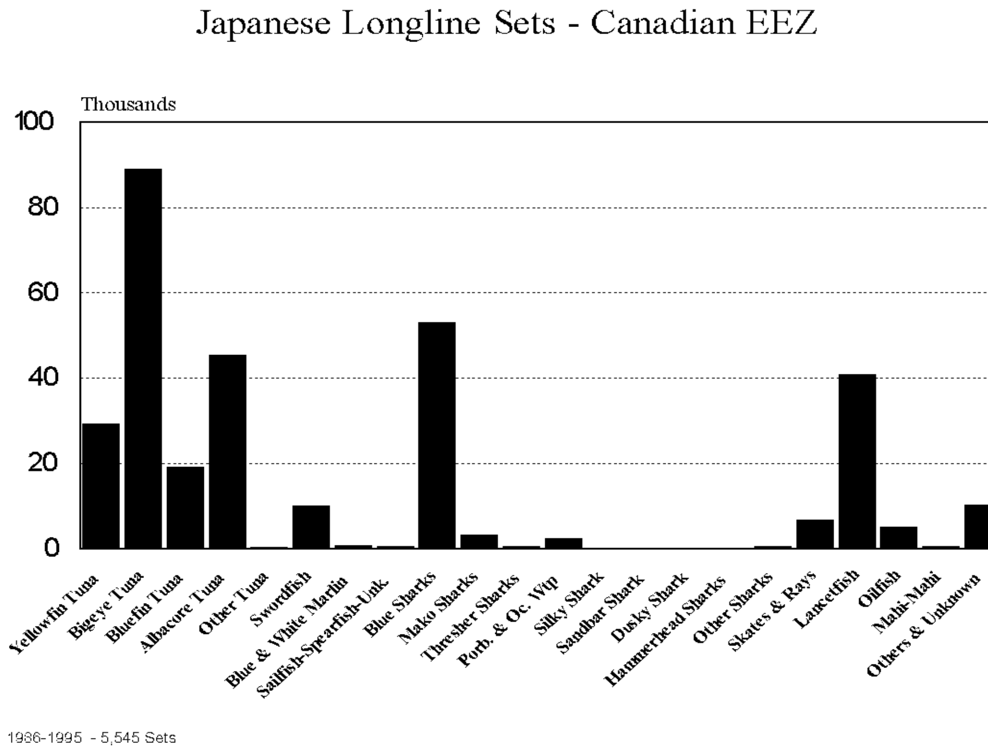

Figure 8. Species composition recorded on 5,545 pelagic longline sets monitored by Canadian observers aboard Japanese vessels fishing within the Canadian EEZ between 1986 and 1995.

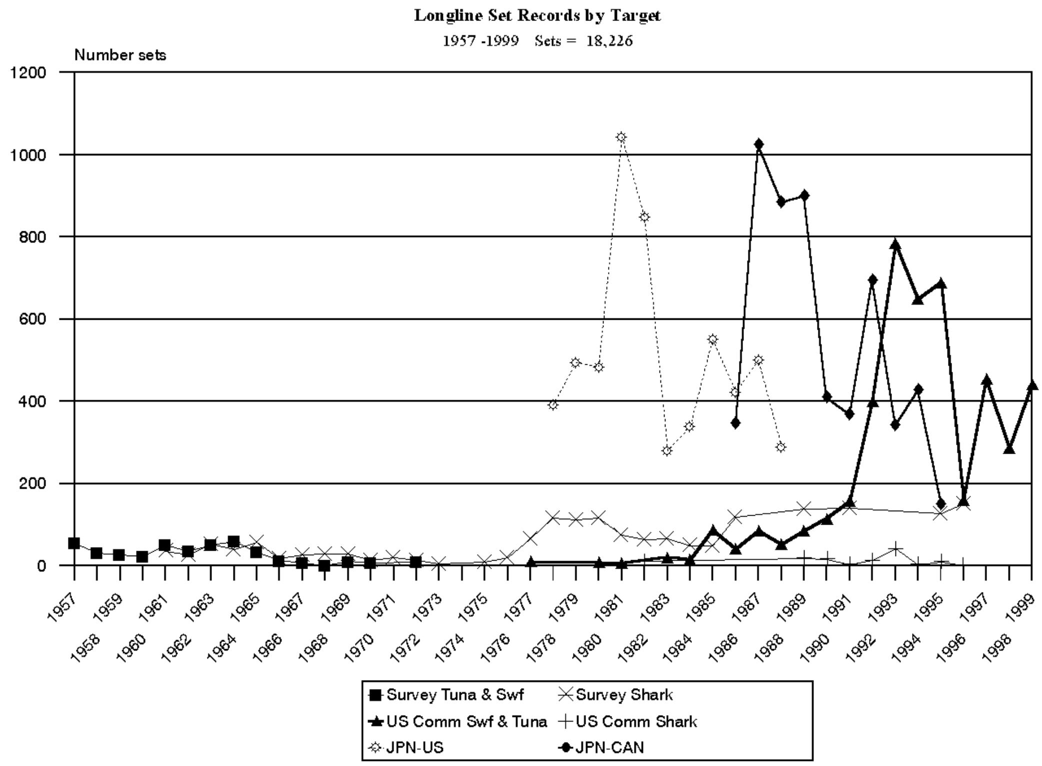

Figure 9. Time series plots of the annual numbers of longline set observations for fishery-dependent and fishery-independent sources of information from the western North Atlantic.

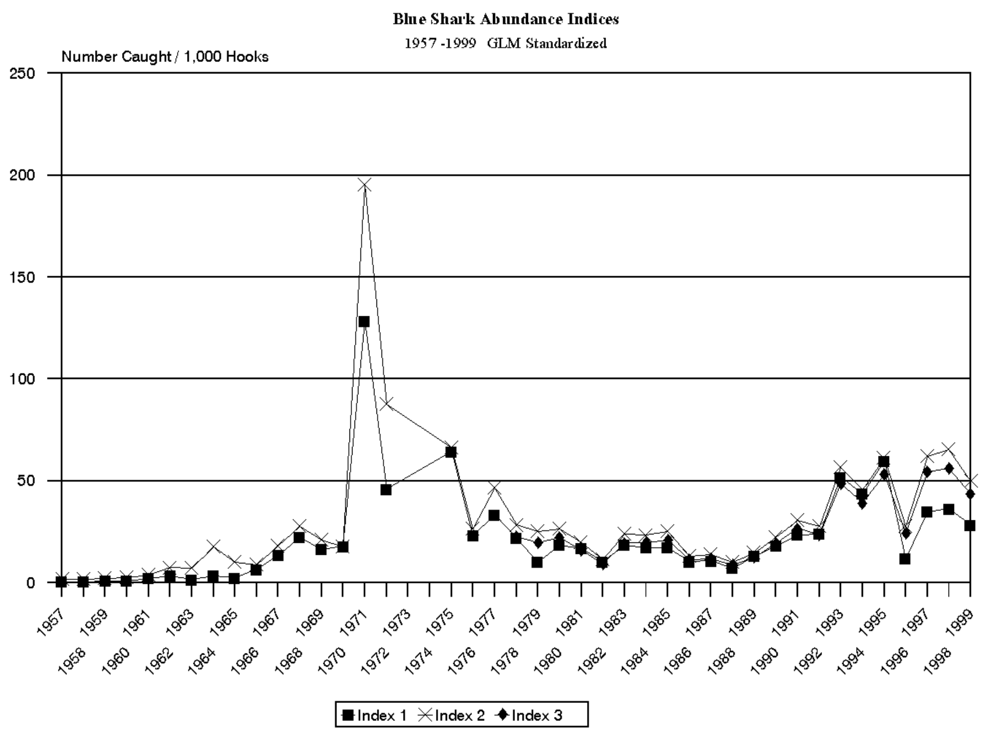

Figure 10. Blue Shark Abundance indices based on GLM standardized catch rates from the western North Atlantic.

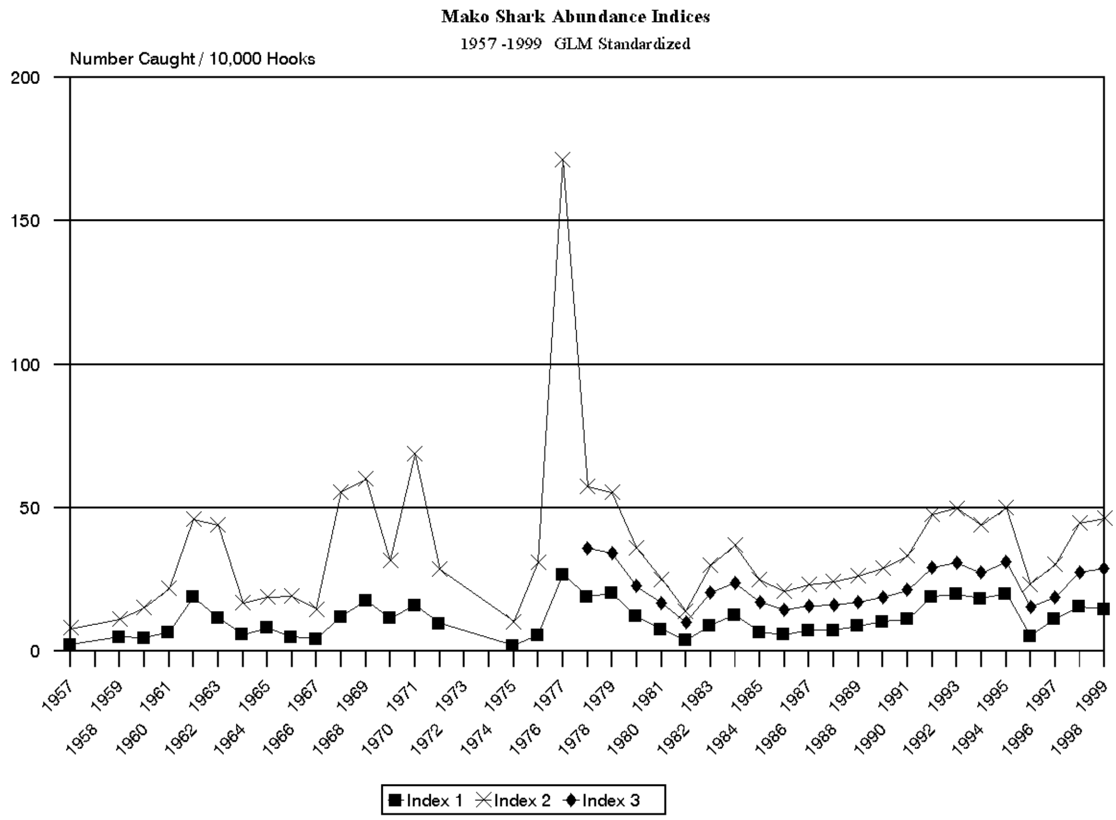

Figure 11. Mako Shark Abundance indices based on GLM standardized catch rates from the western North Atlantic.